THERMAL IMAGING CONTROL OF FURNACES AND COMBUSTORS

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PROJECT TEAM

- Gas Technology Institute
  - control system development and testing
- U. of Illinois at Chicago
  - control algorithm development and control system design
- Owens Brockway Glass Containers
- Commercialization partner
  - two companies under consideration
  - technology demonstration and future development possibilities are important elements in partner selection

PROJECT TEAM - DIRECTION AND SUPPORT

- Gas Research Institute (GRI)
  - direction and funding support
- U.S. DOE
  - direction and funding support through OIT Sensors and Controls
- Owens Brockway
  - cost sharing with internal labor, equipment, and access to facilities
- Commercialization partner
  - Hardware and engineering support for demonstration tests and commitment to commercialization path

OBJECTIVE

The objective of this project is to demonstrate and bring to commercial readiness a near-infrared thermal imaging control system for high temperature furnaces and combustors. The thermal imaging control system, including hardware, signal processing, and control software, is designed to be rugged, self-calibrating, easy to install, and relatively transparent to the furnace operator.

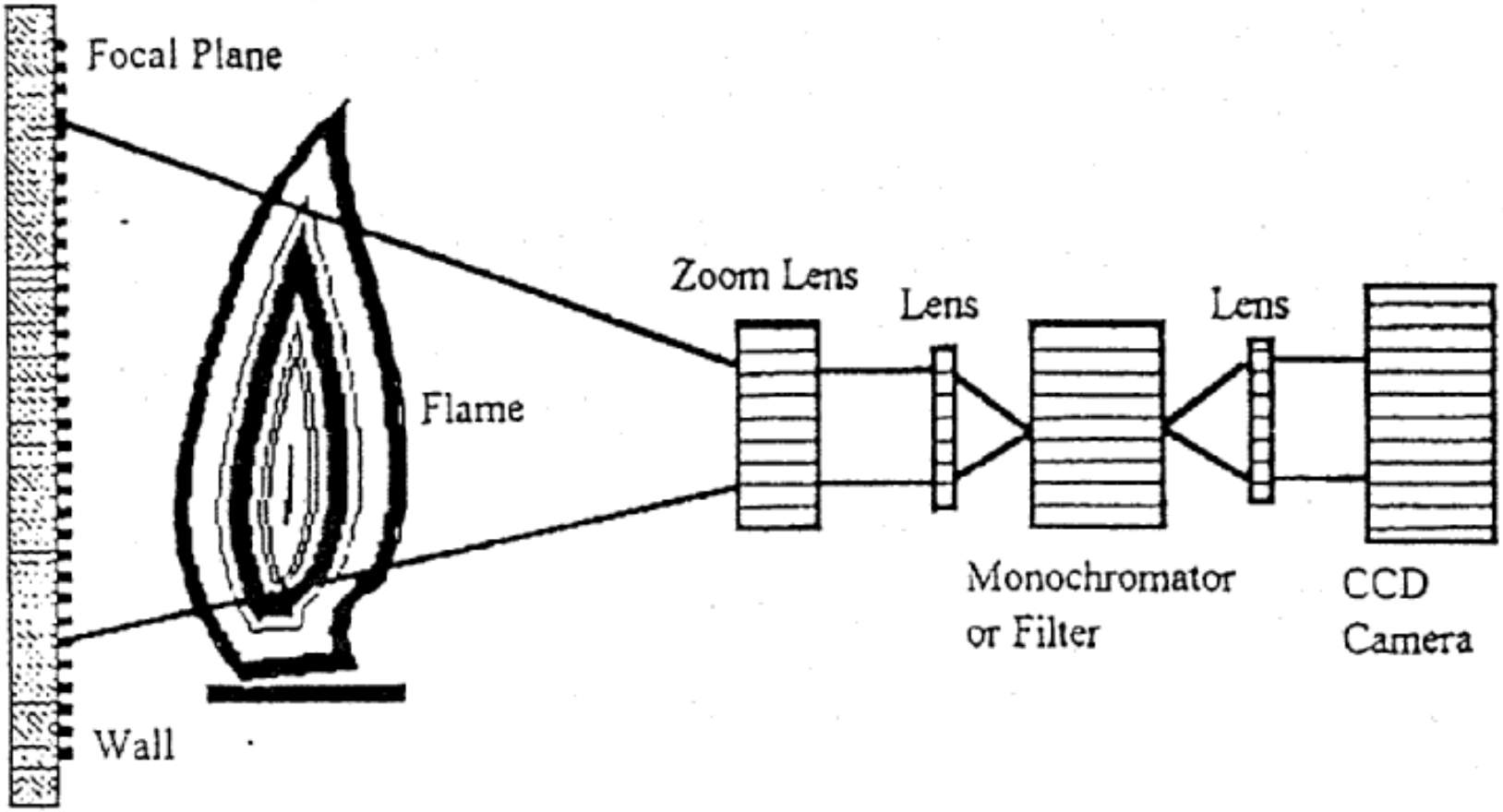
THE NEED FOR THERMAL IMAGING CONTROL

- Traditionally, control systems on multi-burner furnaces
  - change fuel and air to fuel ratios to match one or more **'discrete'** values of temperature, flow, pressure, etc.
  - maintain desired values of several furnace outputs but do **not** optimize the internal performance of a furnace
- Thermal imaging control assists a primary furnace controller by optimizing internal furnace temperatures
- **'Field'** near-IR measurements of all surfaces in the combustion space are compared with a desired temperature map of the combustion space
- Control algorithms minimize differences between the 'field' map and surface temperature in defined areas

ANTICIPATED BENEFITS

- Decreased energy use by 5 percent,
- Reduction in CO and CO_2 production by 5 percent,
- Reduction in NO_x production by 30 percent,
- Elimination of hot spots and instabilities providing longer furnace life and higher product quality,
- Improvements with no major process or equipment changes and at low cost,
- Near-infrared thermal imaging control system is essentially transparent to the operator,
- Thermal imaging system is self-calibrating and adaptable to many types of furnaces,
- Technology is readily acceptable because system assists, but does not replace, existing furnace control.

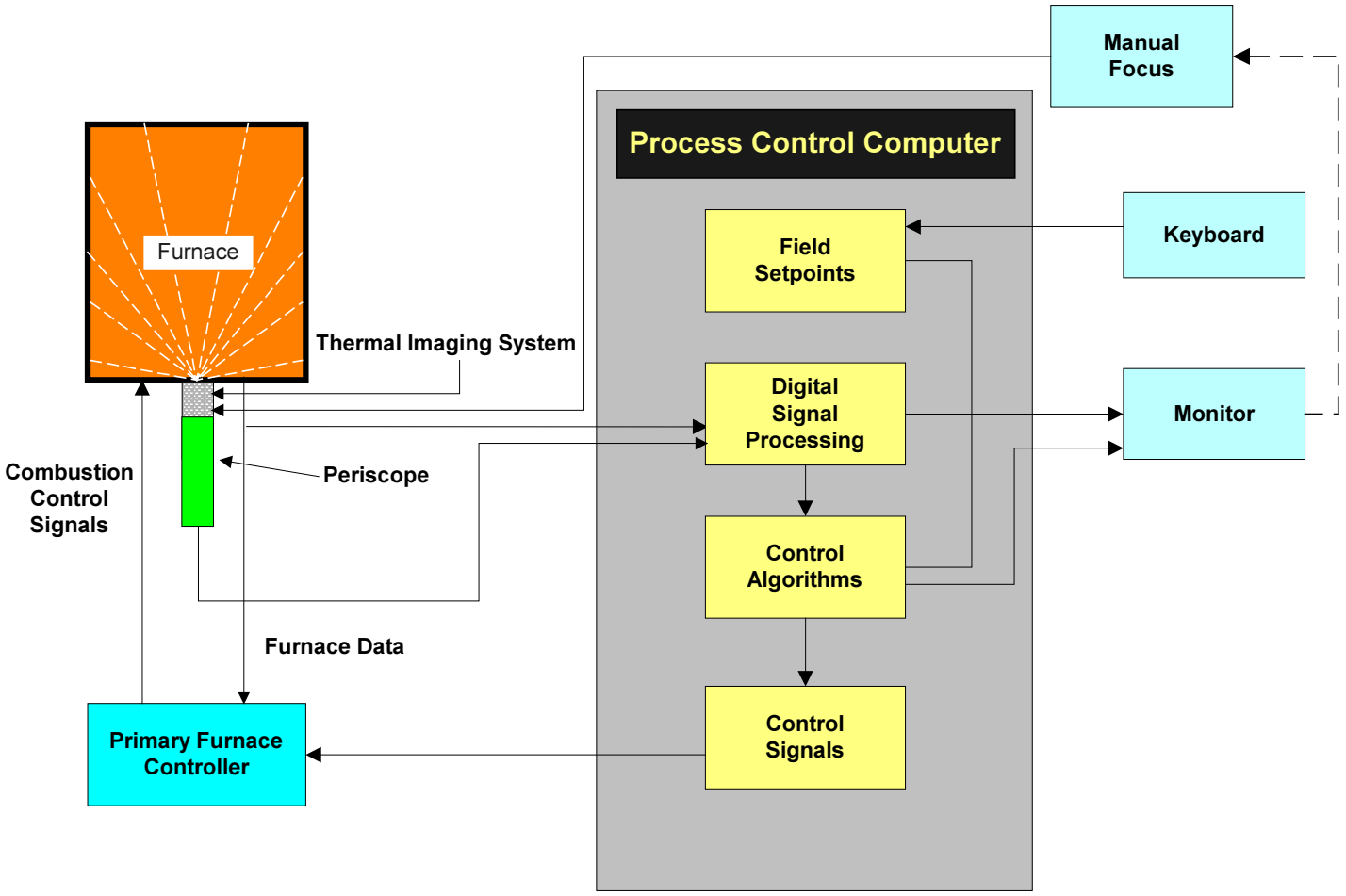
FURNACE IMAGING SYSTEM USING MONOCHROMATOR AND CCD CAMERA



THERMAL IMAGING CONTROL APPROACH

- •• Field temperatures (up to 1 million points, up to 30 times a second) are digitally processed
- •• Results are sent to control algorithms and to a monitor as a false color map
- •• Control algorithms use the field temperature map and control settings to adjust furnace control settings
- •• Feedback control is used to continuously adjust the furnace combustion parameters
- The thermal imaging control system can be either
  - a primary control system component, or
  - a secondary controller assisting the main furnace control system

THERMAL IMAGING CONTROL CONCEPT



PROJECT SCHEDULE

Phase	Task	1999 Jan. ---------- Dec.	2000 Jan. ---------- Dec.	2001 Jan. ---------- Dec.
I. Control System Development	1. System Definition and Industry Needs			
	2. Control System Development		1	
II. Bench-Scale Development	3. Bench-Scale System Assembly		2	
	4. Bench-Scale Evaluation			
	5. Commercialization Plan Outline			3
III. Field Demonstration	6. Field System Assembly			4
	7. Field Evaluation			5
	8. Commercialization Plan			

1. Complete control system design. Go/no go decision for Phase II.
2. Complete bench-scale system design. Must be complete to start Task 4.
3. Complete bench-scale testing and analysis. Go/no go decision for Phase III.
4. Complete field system design. Must be complete to start Task 7.

Achieved goals. Initiate commercialization.

MILESTONES – PHASE I - COMPLETE

- Task 1
  - Select furnace types for thermal imaging / control
  - Survey available sensors and thermal imaging systems
  - Survey available furnace control systems
  - Evaluate thermal imaging system components
- Task 2
  - Select thermal imaging control system components
  - Review control algorithms and devise means to interface with them
  - Develop data collection and processing methods
  - Set up, conduct, and evaluate laboratory tests

PHASE II MILESTONES - ACTIVE

Milestone	Date	Status
Design complete bench-scale thermal imaging / control system	Nov. 2000	Done
Install thermal imaging / control system on bench-scale furnace	March 2001	Done
Complete lab-scale testing and data analysis	May 2001	Done

PHASE III MILESTONES – FUTURE WORK

Milestone	Date	Status
Complete control component for bench-scale furnace	Aug. 2001	In Progress
Demonstrate thermal imaging and control on bench-scale furnace	Sept. 2001	Later
Complete field system design	Nov. 2001	Later
Install thermal imaging control system on industrial furnace(s)	Jan. 2002	Later
Complete field testing and data analysis	March 2002	Later

CAPABILITIES OF THERMAL IMAGINING SYSTEMS

- Measurement of 300,000 to 1,000,000 points
- Scan rate of up to 30 times per second
- Maximum measurement temperature of 3500°F
- High temperature resolution of 1°C
- Near- or mid-IR wavelength(s) used to minimize error and interference
- Used in a wide range of furnaces - kilns, glass tanks, steel reheat, heat treating, etc.
- Systems use either scanned or focal plain arrays

THERMAL IMAGING SYSTEM CAPABILITIES (cont.)

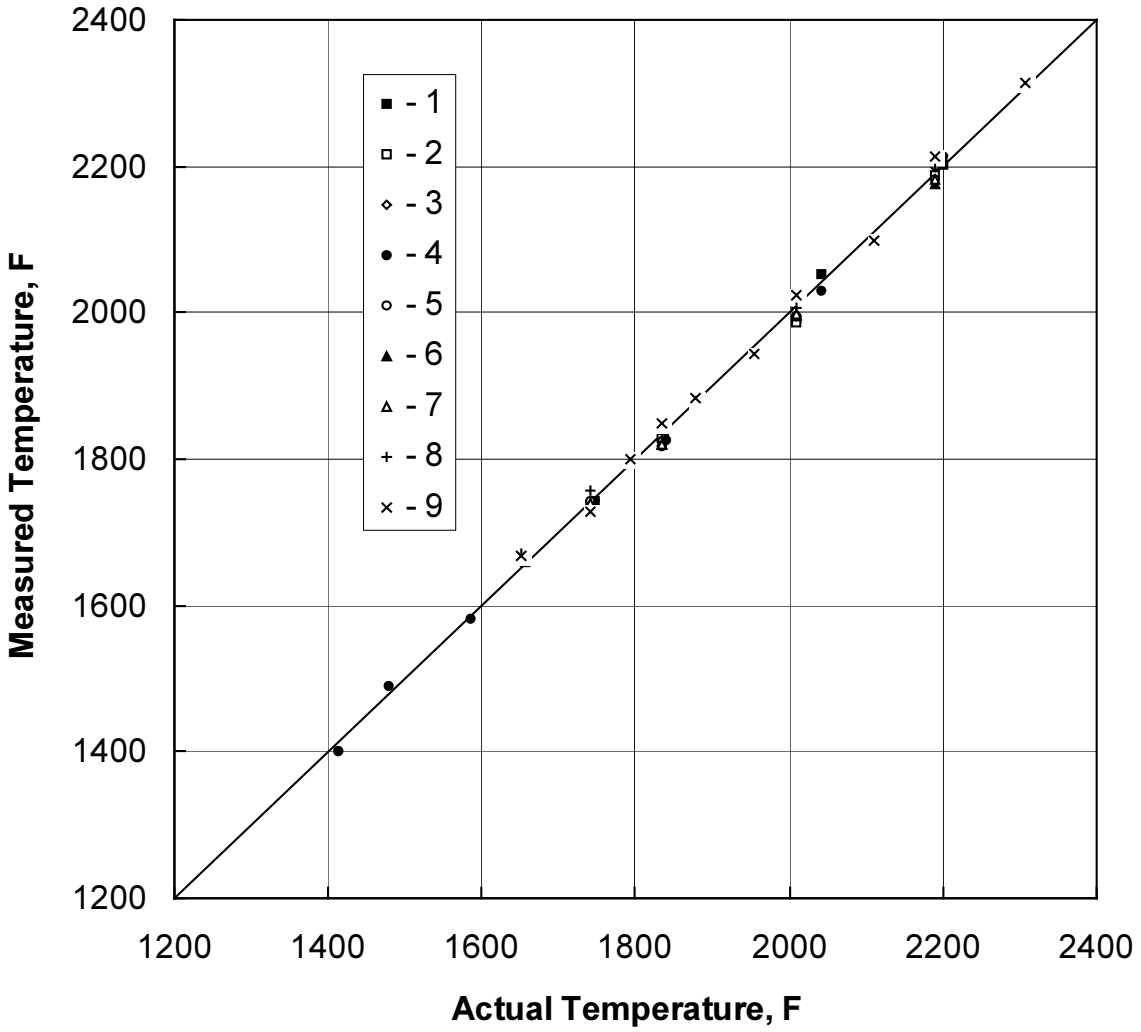
- Sensors can be installed through furnace walls
  - with provisions for external cooling
  - with automated lens clearing
- Self-focusing with focal length of 1 m. to infinity with a standard 50 mm lens
- Measurement accuracy of $\pm$1% or $\pm$1°C
- Detector spatial resolution up to 750 x 500 pixels
- All points stored and available for processing
- Operating humidity of 10 to 95% non-condensing
- Ambient temperature uncooled of 0 to 50°C

CAPABILITIES OF ADVANCED CONTROL SYSTEMS

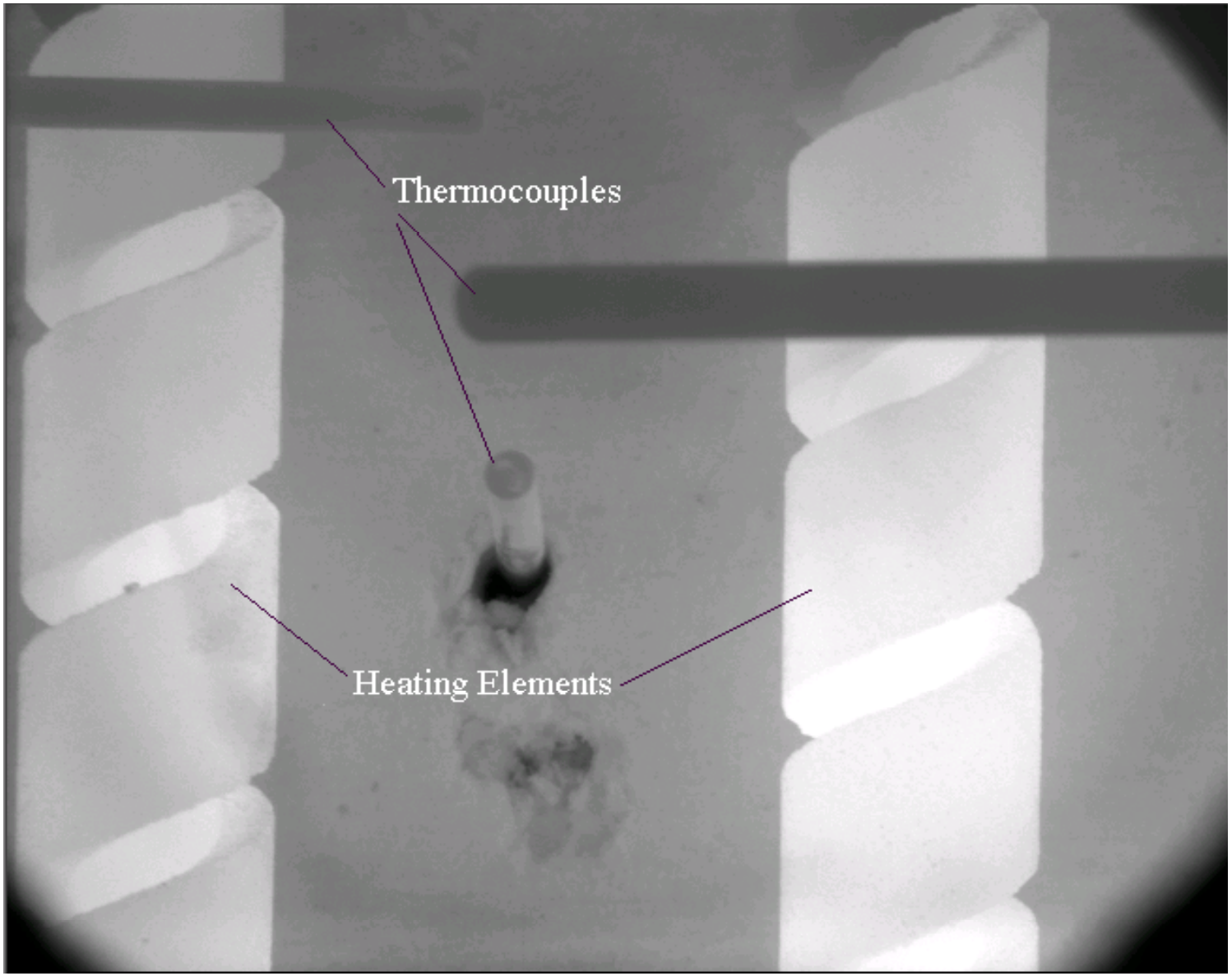
- Multi-variate control
- Systems can handle over 500 control loops
- Flexible control loop design
  - PID and high level control options
  - open architecture
  - capability to accept new types of algorithms
- Text or object-oriented control systems
- Flexible, user-friendly interface software
- Sophisticated data processing software integral to control system with access to all process data

TIS INCLINED SURFACE TESTS

1 – carbon steel (φ = 0°); 2 – carbon steel (φ = 30°); 3 – carbon steel (φ = 60°);
4 – stainless steel (φ = 0°); 5 – stainless steel (φ = 30°); 6 – stainless steel (φ = 45°);
7 – stainless steel (φ = 60°); 8 – stainless steel (φ = 75°); 7 – ceramic (φ = 0°)



GRAY-SCALE IMAGE



PRESENT TEMPERATURE MAP CHARACTERISTICS

- Self calibrating with no emisivity data required
- Repeatable accuracy to $\pm$5°C
- Can be displayed and saved using GTI software (in C++ code) or in Techplot mode
- Temperatures at any location can be acquired with a single mouse click
- Mean temperature can be obtained for any mouse selected area
- Selectable temperature scale - K, F, or C
- Display can be in ‘true color’ (red-yellow) or ‘false color’ (rainbow)
- Temperature map can be monitored in real time with specified degree of dynamic averaging

TEMPERATURE MAP CHARACTERISTICS

Available in the next two months

- Identification of ‘hot’ and ‘cold’ spots
- Mouse selectable areas of interest and monitoring
- Automatic image alignment
- User-friendly ‘set point’ temperature map
  - easy graphical definition of ‘set point’ temperature map
  - comparison of ‘set point’ and real time temperature maps
  - automatic determination of definable ♦T differences
  - storage and output of T and ♦ T data to control operations
- Storage and historical trending of data

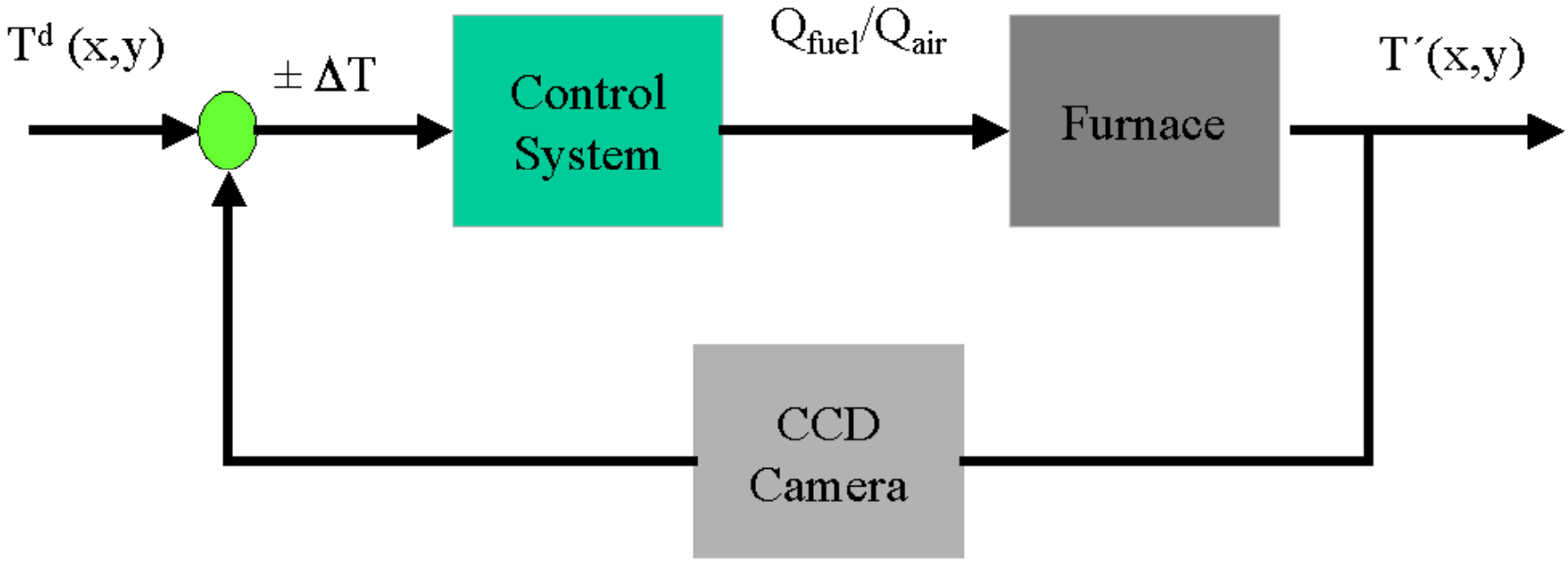
FUTURE TIS DEVELOPMENT

- Complete software integration
  - input interface
  - data storage, processing, output, trending
- Expand temperature range
  - present hardware/software allow 1400-2200°F
  - goal is a range of 750-3500°F
- Put TIS on laboratory heat treating furnace
- Set up furnace with variable load
  - Develop and demonstrate interface that uses load thermal image data to create desired temperature profiles by controlling fan and burners on four radiant tubes
  - Prepare a complete thermal imaging and control package for heat treating furnaces

TOWARD COMMERCIALIZATION

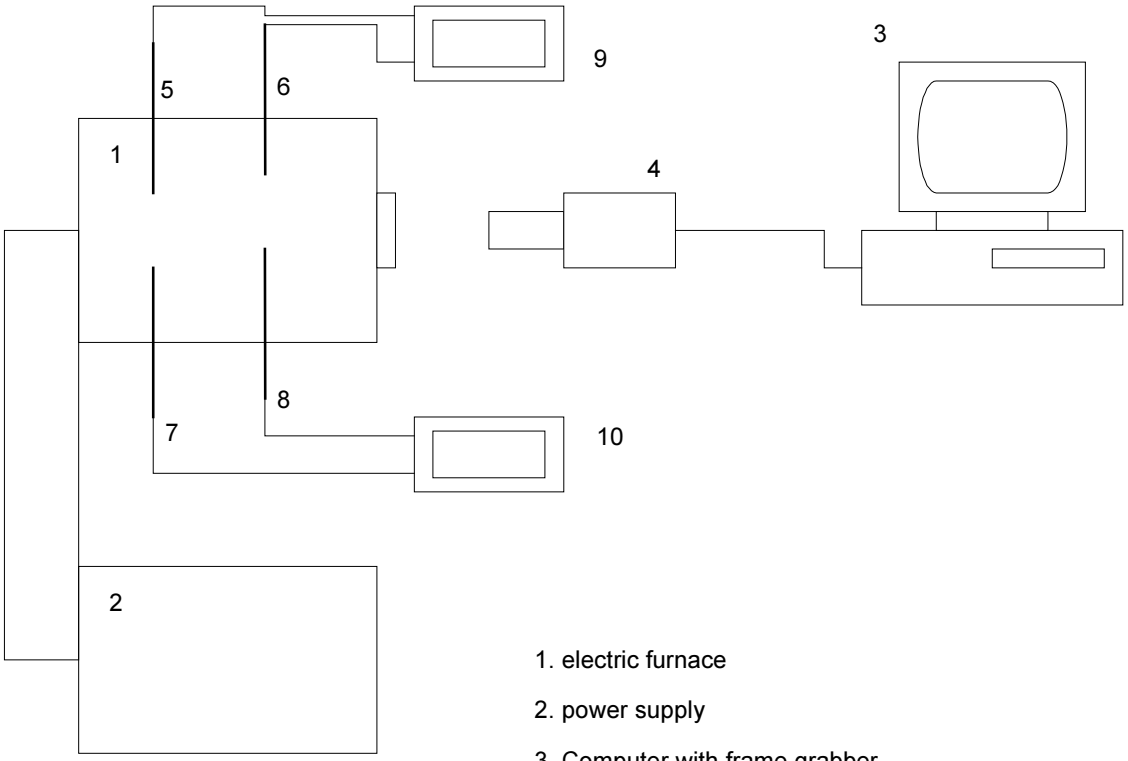
- Discussions in progress with two possible commercializing partners
  - Eclipse and Glass Service for glass furnace MPC control
  - An international engineering and controls firm seeking improved data for control
- Work with commercializing partner(s)
  - demonstration test site selection and testing
  - licensing and planning for commercialization
  - hardware/software packaging for fabrication and sale
- Complete all contract deliverables for DOE / other sponsors

TIS CONTROL APPROACH



T^d (x,y) is the desired temperature distribution
T´(x,y) is the measured temperature distribution

LAB TEST SET UP



1. electric furnace

2. power supply

3. Computer with frame grabber

4.CCD camera, lens and tunable filter

5,6,7,8 thermocouples

9,10 thermocouple readouts

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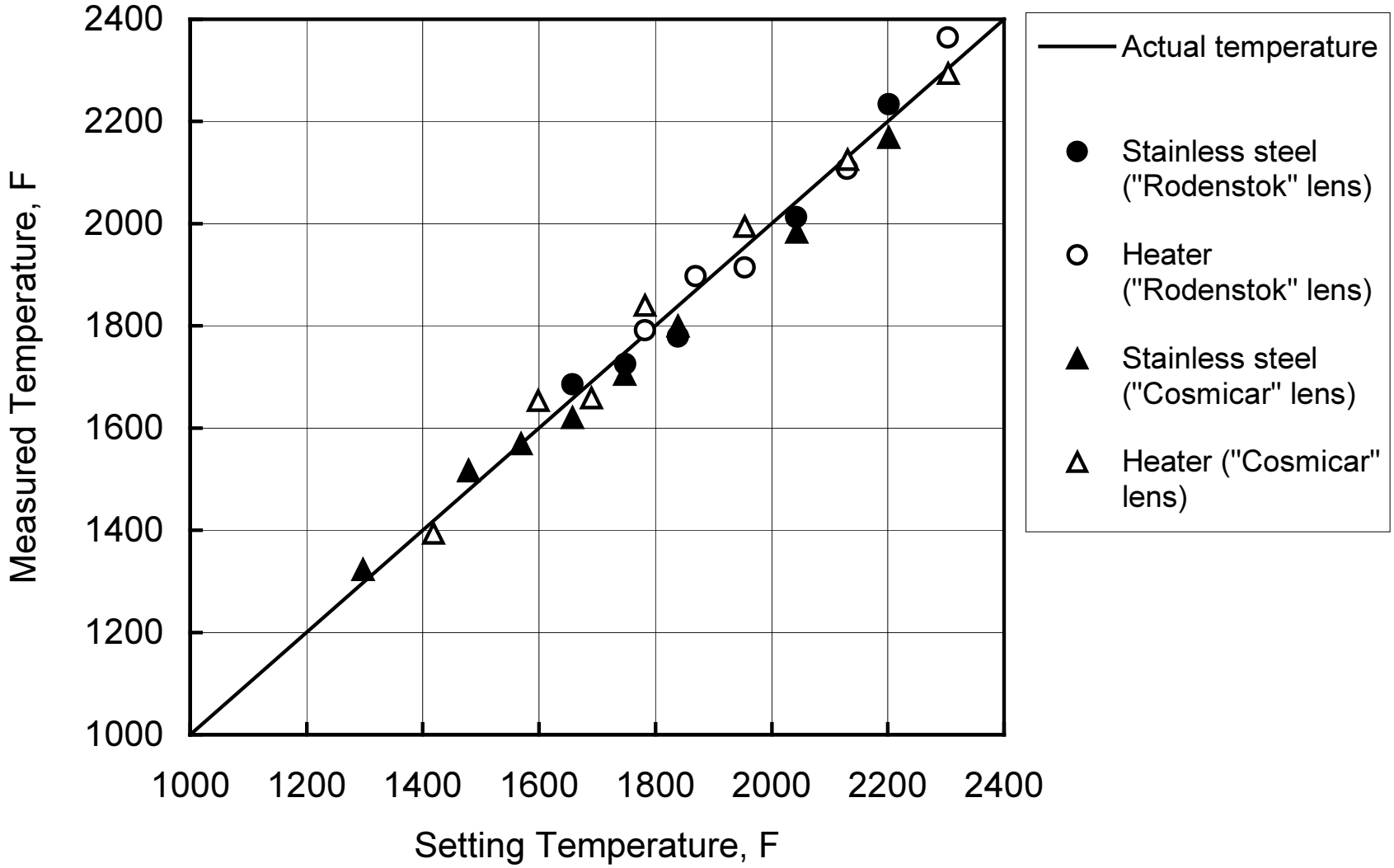
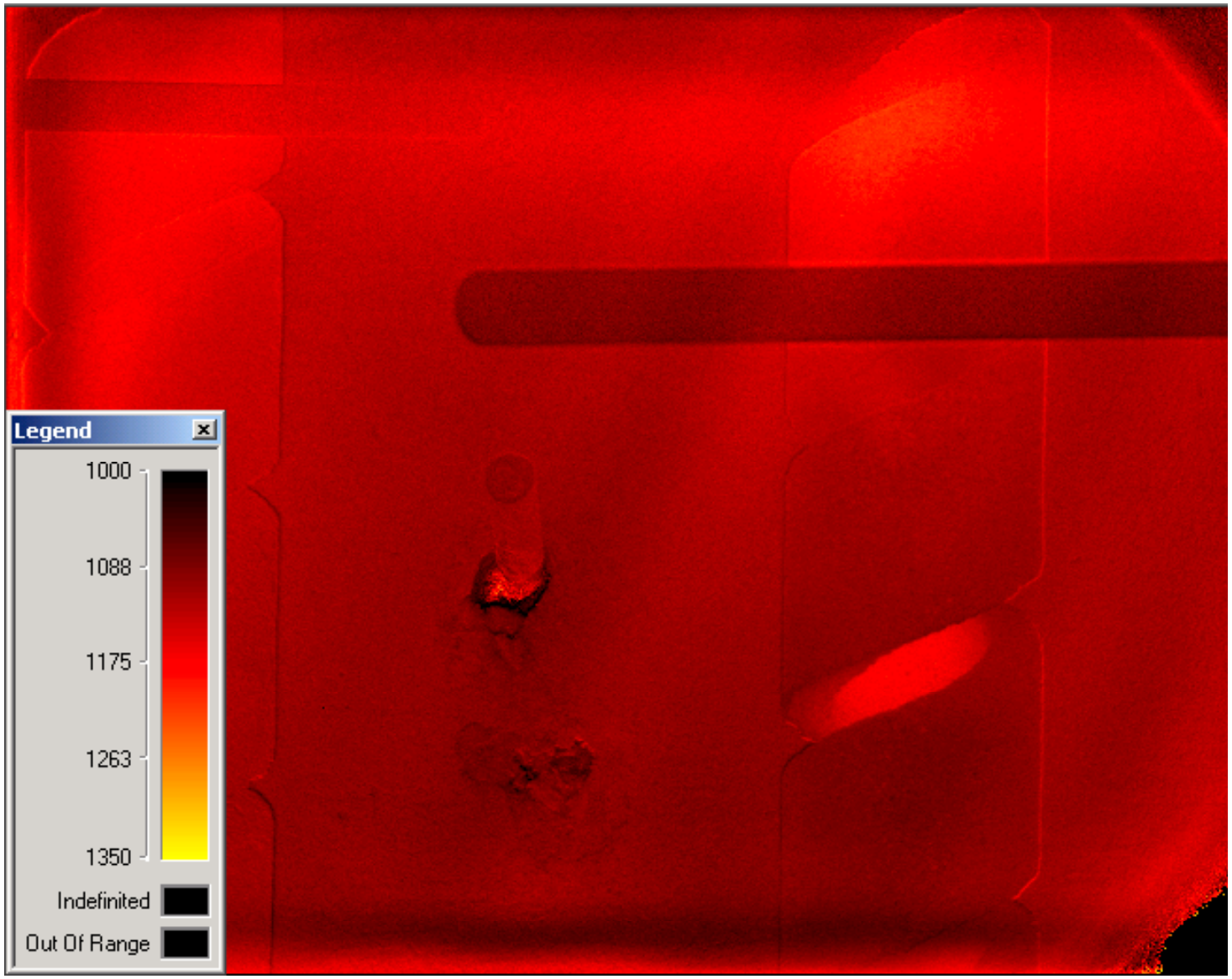
LAB TEST FURNACE

MEASURED VS. ACTUAL TEMP.



TRUE-COLOR TEMP. MAP



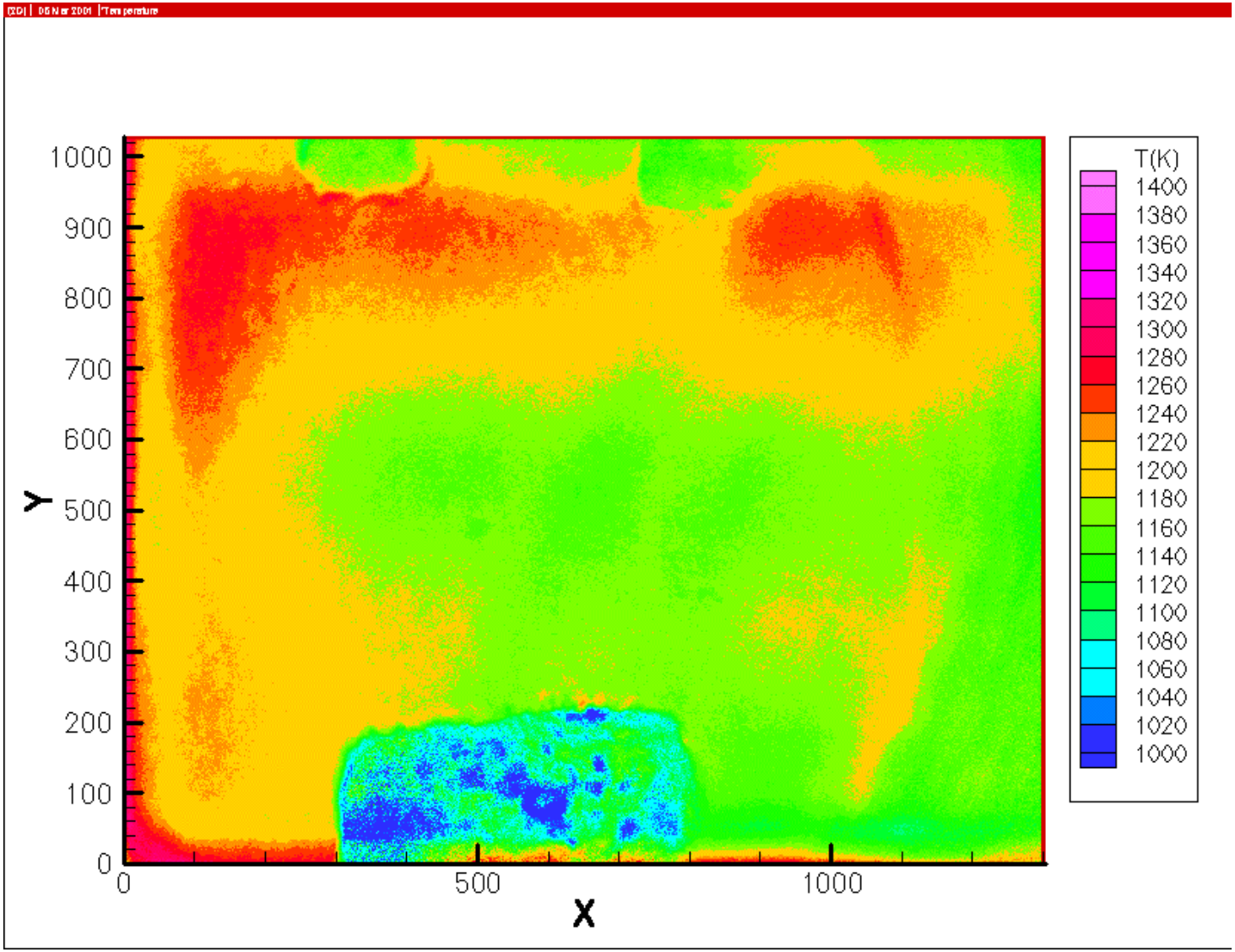
GRAY SCALE (INTENSITY) IMAGE HANDLING

- Acquire gray-scale images in real time
  - grab images
  - store images to disk
- Average gray scale images in two ways
  - applying a weighting factor
  - dynamic averaging of up to 64 images
- Gray scale image intensities can be read as -
  - point value (intensity value at any pixel location)
  - area mean value (mean intensity of any mouse selected area of image)

SOME POTENTIAL TIS APPLICATIONS

- Glass furnaces
- Heat treating furnaces
- Process heaters
- Steel reheat furnaces
- non-ferrous metal furnaces
- Cement kilns
- Long kilns for brick and refractory
- All high temperature multiple burner furnaces

OXY-GAS GLASS FURNACE CERAMIC BURNER BLOCK



HEAT TREATING FURNACE

BENCH-SCALE THERMAL IMAGING SYSTEM


Legend
2200
T, F
1850
1500
1150
800
Indefinited
Out Of Range

PROJECT STATUS

- Basic hardware configuration complete
  - integrated system with no moving parts
  - speed, accuracy, and capacity meet needs using low cost components
- Basic software suite complete
  - self-calibrating real-time temperature maps can be acquired and data used for control
  - accuracy to +5°C with no external inputs
  - advanced software development continuing
- Testing complete on lab furnace
- Preparations under way to test on industrial furnaces